VOLUME VIII: CHAPTER 7

METHODS FOR ESTIMATING GREENHOUSE GAS EMISSIONS FROM MANURE MANAGEMENT

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INTRODUCTION

The purposes of the preferred methods guidelines are to describe emissions estimation techniques for greenhouse gas sources in a clear and unambiguous manner and to provide concise example calculations to aid in the preparation of emission inventories. This chapter describes the procedures and recommended approaches for estimating methane (CH_4) and nitrous oxide (N_2O) emissions from manure management. N_2O emissions from animal waste deposited on the soil (e.g., pasture, range, and paddock) and applied through daily spread operations are addressed in Chapter 9. However, N_2O emissions from other waste management systems are addressed in this chapter.

Section 2 of this chapter contains a general description of the manure management source category. Section 3 provides a listing of the steps involved in using the preferred method for estimating CH_4 and N_2O emissions from this source. Section 4 presents the preferred estimation method; Section 5 is a placeholder section for alternative estimation techniques that may be added in the future. Quality assurance and quality control procedures are described in Section 6. References used in developing this chapter are identified in Section 7.

2

SOURCE CATEGORY DESCRIPTION

2.1 EMISSION SOURCES

Manure decomposition is a process in which microorganisms derive energy and material for cellular growth by metabolizing organic material in manure. When decomposition occurs without oxygen (i.e., anaerobic decomposition), CH_4 is an end product of the process. This overview section will describe the fundamentals of anaerobic decomposition; the CH_4-producing capacity of livestock manure; and the factors that influence CH_4 production from livestock manure.[1] Only manure from animals managed by humans for production of animal products is included in the calculations (i.e., wild animals are excluded).

N_2O is also produced during the manure decomposition process. Estimation of N_2O emissions from animal waste is divided into two methodologies in this volume. The method for calculating direct emissions of N_2O from animal production involving manure management as daily spread or manure that is excreted directly on pasture, range, and paddock is presented in Chapter 9 (*Methods for Estimating Greenhouse Gas Emissions from Agricultural Soils*), Section 4.2. These emissions are considered to be emissions from agricultural soils, whereas emissions from other animal waste management systems are not directly associated with soils and are included in this Chapter. Table 7.2-1 summarizes these and other agricultural and forestry activities associated with emissions of CO_2, CH_4, and N_2O, and provides a roadmap indicating the chapter in which each activity is addressed.

Production of N_2O during the storage and treatment of animal wastes occurs by combined nitrification-denitrification of nitrogen contained in ammonia that is present in the wastes. The amount of N_2O released depends on the system and the duration of waste management. Aeration initiates the nitrification-denitrification reactions (i.e., oxygen is required to begin the nitrification process); thus one would expect increased aeration to cause increased N_2O production. However, there is not yet enough quantitative data to derive a relationship between the degree of aeration and N_2O emissions from slurry during storage and treatment. Because there is very limited information available on N_2O emissions from animal waste during storage and treatment, and there is a very wide range in estimated N_2O losses from those sources, the estimates of N_2O emissions from storage and treatment of animal wastes will not be as accurate as estimates of CH_4 emissions. For more information on the nitrogen cycle, refer to Chapter 9 (*Methods for Estimating Greenhouse Gas Emissions from Agricultural Soils*).

[1] Background information on animal wastes is adapted from Safley et al. (1992a).

Table 7.2-1. GHG Emissions from the Agricultural and Forest Sectors
A check indicates emissions may be significant.

Activity	Associated GHG Emissions and Chapter where these Emissions are Addressed					
	CO_2	Chapter	CH_4	Chapter	N_2O	Chapter
Energy (Farm Equipment)	✔	1	✔	13	✔	13
Animal Production: Enteric Fermentation			✔	6		
Animal Production: Manure Management						
Solid Storage			✔	7	✔	7
Drylot			✔	7	✔	7
Deep Pit Stacks			✔	7	✔	7
Litter			✔	7	✔	7
Liquids/Slurry			✔	7	✔	7
Anaerobic Lagoon			✔	7	✔	7
Pit Storage			✔	7	✔	7
Periodic land application of solids from above management practices					✔	Not included [a]
Pasture/Range (deposited on soil)			✔	7	✔	9
Paddock (deposited on soil)			✔	7	✔	9
Daily Spread (applied to soil)			✔	7	✔	9
Animal Production: Nitrogen Excretion (indirect emissions)					✔	9
Cropping Practices						
Rice Cultivation			✔	8		
Commercial Synthetic Fertilizer Application					✔	9
Commercial Organic Fertilizer Application					✔	9
Incorporation of Crop Residues into the Soil					✔	9
Production of Nitrogen-fixing Crops					✔	9
Liming of Soils	✔	9				
Cultivation of High Organic Content Soils (histosols)	✔	Not included [a]			✔	9
Cultivation of Mineral Soils	✔	Not included [a]				
Changes in Agricultural Management Practices (e.g., tillage, erosion control)	✔	Not included [a]				
Forest and Land Use Change						
Forest and Grassland Conversion	✔	10				
Abandonment of Managed Lands	✔	10				
Changes in Forests and Woody Biomass Stocks	✔	10				
Agricultural Residue Burning			✔	11	✔	11

[a] Emissions may be significant, but methods for estimating GHG emissions from these sources are not included in the EIIP chapters.

The Fundamentals of Anaerobic Decomposition

Livestock manure is primarily composed of organic material and water. Under anaerobic conditions, the organic material is decomposed by anaerobic and facultative bacteria (i.e., bacteria living in the presence or absence of oxygen). The end products of anaerobic decomposition are CH_4, CO_2, and stabilized organic material.

The anaerobic decomposition process can be represented in three stages: hydrolytic; acid forming; and methanogenic. Anaerobic decomposition of carbohydrates in manure proceeds as follows:[2]

- Stage 1: Hydrolytic. In the first stage, complex organic materials in the manure substrate are broken down through the hydrolytic action of enzymes. (Enzymes are proteins formed by living cells that act as catalysts in metabolic reactions.) The amount and rate of breakdown can vary substantially, depending on the enzymes present, the characteristics of the manure, and environmental factors such as pH and temperature.

- Stage 2: Acid Forming. Anaerobic and facultative bacteria reduce (ferment) the simple sugars produced in Stage 1 to simple organic acids. Acetic acid is the primary product of the breakdown of carbohydrates, though other organic acids such as propionic acid and butyric acid can be formed. In addition, metabolic hydrogen and carbon dioxide are produced. With acetic acid as an end product, the breakdown of a simple sugar molecule (glucose) in Stage 2 can be represented as:

$C_6H_{12}O_6$	+	$2H_2O$	$\rightarrow$	$2CH_3COOH$	+	$2CO_2$	+	$4H_2$
glucose	+	water	$\rightarrow$	Acetic acid	+	Carbon dioxide	+	metabolic hydrogen

- Stage 3: Methanogenic. CH_4 producing bacteria (methanogens) convert acetic acids to CH_4 and carbon dioxide (CO_2); and convert metabolic hydrogen and CO_2 into CH_4 and water. Methanogens are strict anaerobes and cannot tolerate the presence of molecular oxygen. Methanogens multiply slowly and are very sensitive to temperature, pH, and substrate composition. With acetic acid, metabolic hydrogen and CO_2 as substrate, the reactions producing CH_4 can be expressed as:

$2CH_3COOH$	$\rightarrow$	$2CH_4$	+	$2CO_2$
acetic acid	$\rightarrow$	Methane	+	Carbon dioxide

$4H_2$	+	CO_2	$\rightarrow$	CH_4	+	$2H_2O$
metabolic hydrogen	+	carbon dioxide	$\rightarrow$	methane	+	Water

[2] This discussion focuses on the decomposition of carbohydrates because carbohydrate decomposition accounts for the majority of the methane produced from livestock manure and because the process of methane production from the decomposition of carbohydrates is best understood. By weight, the volatile solids portion of cattle and swine manure is approximately 40 percent carbohydrate, 15 to 20 percent protein, and up to 10 to 20 percent fat with the remainder composed of other material (Hrubant, Rhodes, and Sloneker, 1978).

<u>CH_4-Producing Capacity of Livestock Manure</u>

In general, livestock manure is highly conducive to CH_4 generation due to its high organic content and large bacterial populations. However, the specific CH_4-producing capacity of livestock manure depends on the specific composition of the manure, which in turn depends on the composition and digestibility of the animal diet. The greater the energy content and digestibility of the feed, the greater the CH_4-producing capacity of the resulting manure. For example, feedlot cattle eating a high energy grain diet produce highly biodegradable manure with a high CH_4-producing capacity. Range cattle eating a low energy forage diet produce a less biodegradable manure with only half the CH_4-producing capacity of feedlot cattle manure.

In principle, the CH_4 producing capacity of a quantity of manure could be predicted from the gross elemental composition of the manure. In practice, however, data have not been collected to implement this approach and the CH_4-producing capacity is instead determined through direct laboratory measurement. The CH_4-producing capacity of livestock manure is generally expressed in terms of the quantity of CH_4 that can be produced per kilogram of volatile solids (VS) in the manure.[3] This quantity is commonly referred to as B_o with units of cubic feet of CH_4 per pound VS (ft^3 CH_4/ lb VS). Representative B_o values for a number of livestock manure types are presented later in this chapter.

2.2 FACTORS INFLUENCING EMISSIONS

Methane

While a particular quantity of manure may have a certain potential to produce CH_4 based on its volatile solids content, the manure management system and the climate in which the manure is managed are major factors influencing the amount of CH_4 actually produced during manure decomposition.

The characteristics of the manure management systems and climate can be expressed in a methane conversion factor (MCF) which represents the extent to which the potential for emitting CH_4 is realized. Manure management systems and climate conditions that promote CH_4 production will have an MCF near 1, while manure management systems and climate conditions that do not promote CH_4 production will have an MCF near 0. The primary characteristics determining the MCF are:

<u>Manure Management System Factors</u>

- *Contact with Oxygen*. Under aerobic conditions where oxygen is in contact with the manure, there is no potential for CH_4 production.

[3] Volatile solids (VS) are defined as the organic fraction of the total solids (TS) in manure that will oxidize and be driven off as gas at a temperature of 1,112° F. Total solids (TS) are defined as the material that remains after evaporation of water at a temperature between 217° and 221° F.

- *Water Content*. Liquid-based systems promote an oxygen-free environment and anaerobic decomposition. In addition, water is required for bacterial cell production and metabolism, and acts as a buffer to stabilize pH. Moist conditions increase the potential for CH_4 production.

- *pH*. CH_4-producing bacteria are sensitive to changes in pH. The optimal pH is near 7.0 but CH_4 can be produced in a pH range between 6.6 and 8.0.

- *Nutrients*. Bacterial growth depends on the availability of nutrients such as nitrogen, phosphorus, and sulfur. Deficiency in one or more of these nutrients will inhibit bacterial growth and CH_4 formation. Animal diets typically contain sufficient nutrients to sustain bacterial growth. Therefore, under most circumstances, nutrient availability is not a limiting factor in CH_4 production.

<u>Climate Factors</u>

- *Temperature*. Temperature is one of the major factors affecting the growth of the bacteria responsible for CH_4 formation (Chawla, 1986). Although methanogenesis in livestock manure has been observed between 39° F and 167° F, the rate of CH_4 production generally increases with rising temperature.

- *Moisture*. For non-liquid-based manure systems, the moisture content of the manure is determined by rainfall and humidity. The moisture content of the manure will determine the rate of bacterial growth and decomposition. Moist conditions promote CH_4 production.

<u>Management System and Climate Factors Combined</u>

The management system and climate factors can be combined into the following expression for estimating <u>realized</u> CH_4 emissions from livestock manure:

$$\text{Realized } CH_4 \text{ emissions} = B_o \times \text{MCF} \tag{7.1}$$

Where B_o= the maximum CH_4 producing capacity of the manure determined by animal type and diet (ft^3 CH_4/lb VS).

MCF = Methane Conversion Factor (MCF) that represents the extent to which the B_o is realized for a given livestock manure management system and environmental conditions. Note: $0 \le \text{MCF} \le 1$.

Nitrous Oxide

The quantity of N_2O produced depends on the manure and urine composition, the type of bacteria involved in the decomposition process, and the amount of oxygen and liquid present in the manure management system.

3

OVERVIEW OF AVAILABLE METHODS

3.1 OVERVIEW OF PREFERRED METHOD FOR ESTIMATING CH_4 EMISSIONS FROM MANURE MANAGEMENT

As discussed above, CH_4 emissions from livestock manure depend on the type of manure, the characteristics of the manure management system, and the climatic conditions in which the manure decomposes. Although limited data are available on which to base emission estimates, a study prepared for the U.S. EPA provides an adequate basis for making estimates (Safley et al., 1992a).

Based on the Safley et al. (1992a) approach, manure CH_4 emission estimates are developed by:

- Identifying the manure management systems in use in the United States;
- Estimating the amount and type of manure managed by each system; and
- Estimating emissions by multiplying the amount of manure managed in each system by the estimated emission rate per unit of manure in the system.

Methods for developing greenhouse gas inventories are continuously evolving and improving. The methods presented in this volume represent the work of the EIIP Greenhouse Gas Committee in 1998 and early 1999. This volume takes into account the guidance and information available at the time on inventory methods, specifically, U.S. EPA's *State Workbook: Methodologies for Estimating Greenhouse Gas Emissions* (U.S.EPA 1998a), volumes 1-3 of the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC, 1997), and the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 1996* (U.S. EPA 1998b).

There have been several recent developments in inventory methodologies, including:

- Publication of EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 1997* (U.S. EPA 1999) and completion of the draft inventory for 1990 – 1998. These documents will include methodological improvements for several sources and present the U.S. methodologies in a more transparent manner than in previous inventories;
- Initiation of several new programs with industry, which provide new data and information that can be applied to current methods or applied to more accurate and reliable methods (so called "higher tier methods" by IPCC); and
- The IPCC Greenhouse Gas Inventory Program's upcoming report on Good Practice in Inventory Management, which develops good practice guidance for the implementation of the 1996 IPCC Guidelines. The report will be published by the IPCC in May 2000.

Note that the EIIP Greenhouse Gas Committee has not incorporated these developments into this version of the volume. Given the rapid pace of change in the area of greenhouse gas inventory methodologies, users of this document are encouraged to seek the most up-to-date information from EPA and the IPCC when developing inventories. EPA intends to provide periodic updates to the EIIP chapters to reflect important methodological developments. To determine whether an updated version of this chapter is available, please check the EIIP site at http://www.epa.gov/ttn/chief/eiip/techrep.htm#green.

Total emissions will equal the quantity of volatile solids managed in each system, times emissions per kilogram of volatile solids (VS) for that system. Safley et al. (1992a) demonstrated that CH_4 emissions are driven by four main factors: the quantity of VS produced; the B_o values for the manure; the MCFs for the manure management systems; and the portion of the manure handled by each manure management system (WS%). Refer to Safley et al (1992a) for equations and the procedure used to estimate these CH_4 emissions.

The method described here is taken from the report by the Intergovernmental Panel on Climate Change (IPCC) entitled *IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 1997). This method is used in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1997* (U.S. EPA 1999). The IPCC is developing supplemental guidance (Good Practice Guidance) for countries to use as they develop national greenhouse gas emission inventories. The Guidance is expected to be published in spring 2000, and could be used by states to improve this inventory methodology.

3.2 OVERVIEW OF PREFERRED METHOD FOR ESTIMATING N_2O EMISSIONS FROM MANURE MANAGEMENT

To estimate emissions of N_2O from manure management, not including manure used as daily spread or manure that is excreted directly on pasture, range, and paddock, 3 steps should be performed:

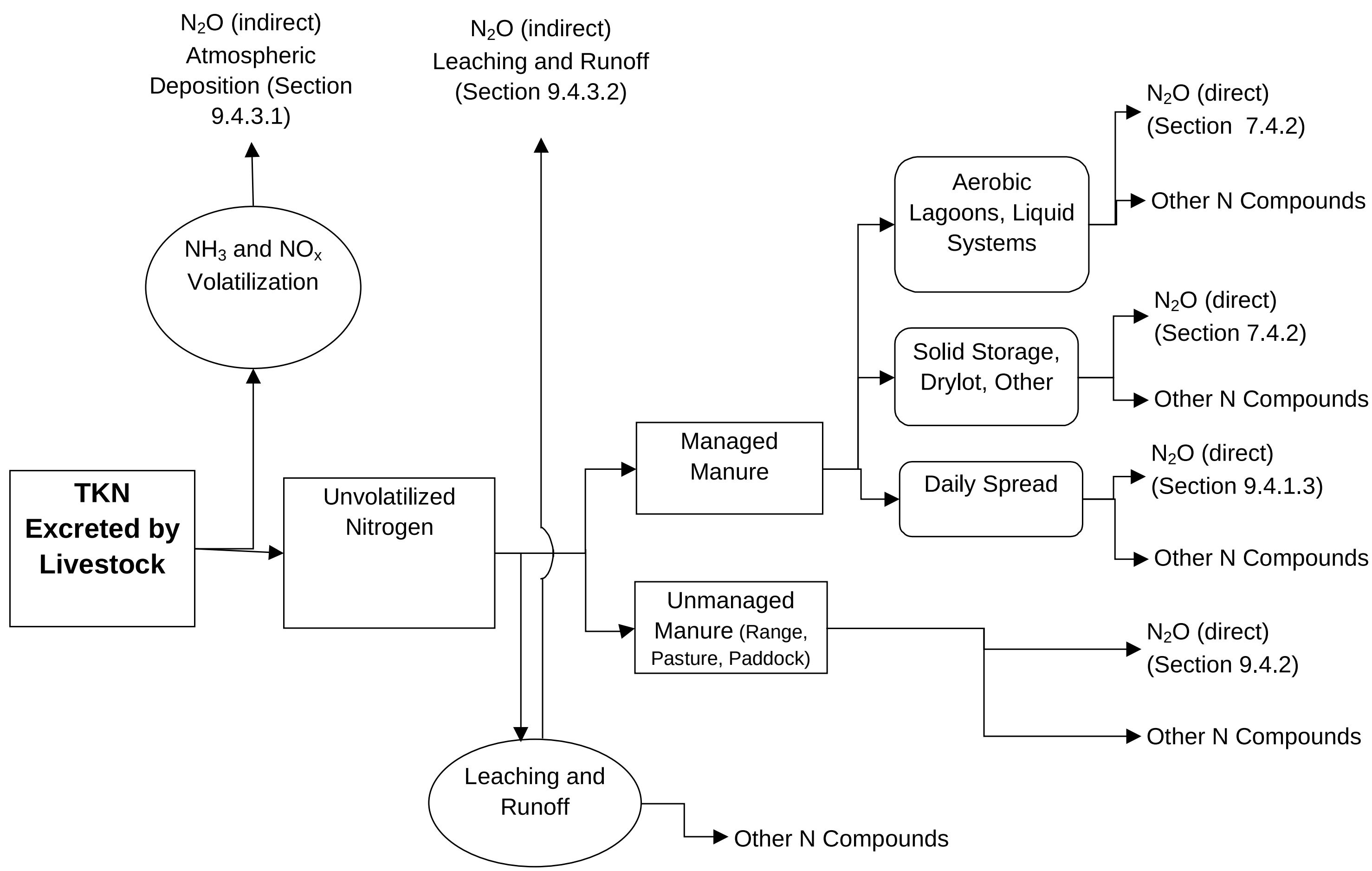
> **Step 1:** Obtain the required data to calculate the amount of manure managed--excluding manure managed as "daily spread" (i.e., spread daily on cropland and pasture), or that is deposited directly by grazing livestock in pastures and paddocks--and the nitrogen content of the excretion.
> **Step 2:** Use the data to calculate the amount of manure managed.
> **Step 3:** Calculate N_2O emissions from manure management.

This method is also taken from the report by the Intergovernmental Panel on Climate Change (IPCC) entitled *IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC 1997), and used in the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1997* (U.S. EPA 1999). Alternative methods of quantifying N_2O emissions from agricultural activities are under development. The aforementioned IPCC Good Practice Guidance, which will be published in spring 2000, could be used by states to improve this inventory methodology. Additionally, researchers are working on a modeling approach that considers nitrogen stocks and flows and how they relate to soil systems. This approach could provide a more holistic approach to accounting for N_2O emissions from agricultural activities on soils. Figure 7.3-1 traces the flow of nitrogen from livestock and indicates the section where N_2O emissions from each step are addressed (note that several emission sources are addressed in other chapters).

3.3 HARMONIZING THESE METHODS WITH ESTIMATES FOR DOMESTICATED ANIMALS

Emissions estimates for manure management and domesticated livestock rely on the same underlying livestock population data and livestock characteristics data. It is important to use the same underlying data to estimate emissions from these two sources. One way to ensure consistency is to use USDA National Agriculture Statistics Service (NASS) data to estimate the livestock populations for both sources. Although the standard categories of livestock types vary between the methods for the two sources, they are internally consistent and rely on the same underlying USDA/NASS population data. If the Alternative Method for cattle is used to estimate emissions from domesticated animals (this method is described in Chapter 6, section 5), an effort should be undertaken to make the estimates from manure management consistent with the cattle populations and characteristics developed for that method. This effort should focus on the sizes of the cattle (their typical animal mass) and their amount of manure production, which are important factors in the emissions estimates for manure management. The estimates of the sizes of the cattle should be adjusted to ensure that the sizes are the same for both sources.

Figure 7.3-1. Nitrogen Flows Related to Livestock



4

PREFERRED METHOD FOR ESTIMATING EMISSIONS

4.1 CH_4 EMISSIONS FROM ANIMAL MANURE

To estimate CH_4 emissions from animal manure, the following steps should be performed: (1) obtain the required data on animal populations and manure management practices; (2) calculate the amount of volatile solids (VS) produced by each animal; (3) estimate CH_4 emissions from each manure management system; (4) convert emissions to tons of CH_4; (5) sum estimates to obtain total annual CH_4 emissions for the state; and (6) convert to units of metric tons of carbon equivalent (MTCE). Each of these steps is outlined in detail below. A worksheet is provided in Table 7.4-16 to assist in the calculations through Step (5).

Step (1) Obtain Required Data

- *Required Data.* To estimate CH_4 emissions from manure, information is needed on annual average animal populations for the following animal types: cattle (by type), swine (by type), poultry (by type), sheep, goats, donkeys, horses, and mules (see Table 7.4-1 for further detail).

  In addition, data are needed on the percentage of each type of animal manure handled in each type of manure management system.

- *Data Sources.* Departments within each state responsible for conducting agricultural research and monitoring agricultural waste practices should be consulted for animal population data. Alternatively, animal population data are provided by the National Agriculture Statistics Service of the U.S. Department of Agriculture (USDA) and can be found at the following Internet address: http://usda.mannlib.cornell.edu/cgi-usda/agency.cgi?nass. When using this data source, a state's annual average population of a given animal type may be estimated as described in chapter 6 of this volume. Animal population data may also be found in the *Census of Agriculture, Volume 1: Geographic Area Series,* (e.g., Bureau of the Census, 1987).

  Data are provided on the percentage breakdown of the systems used to manage manure, for most states and manure management systems, in Tables 7.4-2 to 7.4-10.

- *Units for Reporting Data.* Animal population should be reported in number of head. Data on the amount of animal manure handled in each type of manure management system should be reported as percentages.

Table 7.4-1
Recommended Representative Animal Types

Main Categories	Sub-Categories
Mature Dairy Cattle	Milk Cows: used principally for commercial milk production
Mature NonDairy Cattle	Mature Females: -- Beef Cows: used principally for producing beef steers and heifers -- Multiple-Use Cows: used for milk production, draft power, and other uses Mature Males: -- Breeding Bulls: used principally for breeding purposes -- Draft Bullocks: used principally for draft power
Young Cattle	Pre-Weaned Calves Growing Heifers, Steers/Bullocks, and Bulls Feedlot-Fed Steers and Heifers on High-Grain Diets
Swine	Market: used principally for commercial pork products. Breeding: used principally for breeding.
Poultry	Layers Broilers Ducks Turkeys
Other Animals	Sheep Goats Donkeys Horses/Mules

Step (2) Calculate the Amount of Volatile Solids (VS) Produced. (Enter on Table 7.4-16, Columns A, B, C, and D)

CH_4 emissions from livestock are directly related to the amount of volatile solids (VS) produced. The data required to estimate total VS production for a given animal type *i* are the number of animals (N_i), average size (TAM_i), and average VS production per unit of animal size (VS_i).

In the U.S., considerable data are available to allow the populations of animals to be categorized by species, production system, and (for cattle) age. Six main categories of animals have been defined: feedlot beef cattle;[4] other beef cattle; dairy cattle; swine; poultry; and other. These main categories have been further divided into 17 subcategories. For each subcategory, VS production has been estimated using data on the animal population, the typical animal mass (TAM), and the VS production per unit of animal mass. Table 7.4-11 lists the data obtained for the 17 subcategories.

- For each animal type *i*, multiply the animal population by the typical animal mass (TAM_i) and the average annual volatile solids production per unit of animal mass (VS_i), using data provided in Table 7.4-11.

  $$\text{Animal}_i \text{ Population (head)} \times TAM_i \text{ (lbs/head)} \times VS_i \text{ (lbs. VS/lb. animal mass/yr)} = \text{Total } VS_i \text{ produced (lbs/yr)}$$

> ***Example*** The total amount of volatile solids (VS) produced by milk cows in Ohio for 1997 is calculated as follows:
>
> 315,315 head x 1,345 lbs/hd. x 3.65 lbs VS/lb animal mass/yr = **1.55 billion lbs/yr**

Step (3) Estimate CH_4 Emissions for Each Manure Management System (Enter on Table 7.4-16, Columns E, F, G, H, and I)

CH_4 emissions from livestock depend upon animal type and diet, in addition to the manure management system employed. A large variety of manure management systems exist in the U.S., each requiring different methane conversion factors to estimate CH_4 emissions.

- For each animal type *i* and manure system *j*, multiply the amount of volatile solids produced (VS_i) by the CH_4 producing capacity of the manure (B_{oi}) times the CH_4 producing potential (MCF_j) of the manure system times the percent of the animals' manure that is managed in that manure system ($WS\%_{i\,j}$). Default values for B_o and MCF

[4] Feedlot cattle are animals fed a ration of grain, silage, hay and protein supplements for the slaughter market (ASB, 1991).

by state are presented in Tables 7.4-13 through 7.4-15.[5] WS% values for most states, animal types, and management practices are provided in Tables 7.4-2 to 7.4-10.

$$VS_i \times B_{oi} \times MCF_j \times WS\%_{ij} = CH_4 \text{ Emissions for animal } i \text{ in system } j \ (ft^3\ CH_4)$$

where:

VS_i = total volatile solids produced (lbs./yr) for animal *i*;

B_{oi} = maximum CH_4 producing capacity per pound of VS for animal *i* (ft^3/lb-VS);

MCF_j = methane conversion factor for manure system *j* (%);

$WS\%_{ij}$ = percent of animal *i*'s manure managed in manure system *j* (%).

Example Total annual CH_4 emissions from milk cows in Ohio on a daily spread manure management system are calculated as follows:

1.55 billion lbs./yr x 3.84 (ft^3 CH_4/lb.-VS) x 0.2% x 45% = **5.4 million ft^3 CH_4/yr**

Step (4) Convert to Tons of CH_4 (Table 7.4-16, Column J)

- For each animal *i* and manure management system *j* multiply CH_4 emissions by the density of CH_4 (0.0413 lbs/ft^3) to convert from cubic feet to pounds.
- Divide the results by 2000 to obtain CH_4 emissions from each animal and manure management system in tons.

Example Annual CH_4 emissions from milk cows in Ohio in a daily spread manure management system [from Step(3)] are converted from cubic feet to tons as follows:

(a) 5.4 million ft^3 CH_4/yr x 0.0413 lbs/ft^3 = 220,000 lbs CH_4/yr

(b) 220,000 lbs CH_4/yr ÷ 2000 lbs/ton = **110 tons CH_4/yr**

[5] Lower B_o values for swine and increased MCF for lagoons have been suggested as part of the IPCC's Good Practice process. States are encouraged to refer to the IPCC report on Good Practice in Inventory Management due to be published in May 2000.

Step (5) Estimate Total Annual CH_4 Emissions

- Sum across all animal types i and all manure management systems j to obtain total CH_4 emissions from animal manure.
  $$\text{Total Annual } CH_4 \text{ Emissions (tons } CH_4) = \sum_i \sum_j \text{Total } CH_4 \text{ Emissions}_{ij} \text{ (tons } CH_4)$$

Step (6) Convert to Units of Metric Tons of Carbon Equivalent (MTCE)

To convert the units to MTCE, first multiply the value for tons of methane by 0.91 to obtain the value for metric tons of methane. Then multiply by 12/44 (the ratio of the molecular weight of carbon to the molecular weight of CO_2), and by 21 (the global warming potential of methane). The result is methane emissions in units of metric tons of carbon equivalent (MTCE).

Table 7.4-2: Percentage Breakdown of Manure Management Systems for U.S. Beef

STATE	Anaerobic Lagoon	Drylot	Liquid/ Slurry	Pasture	Other
AL	0%	2%	0%	98%	0%
AK	0%	0%	0%	100%	0%
AZ	0%	30%	0%	70%	0%
AR	0%	1%	0%	99%	0%
CA	0%	12%	0%	88%	0%
CO	0%	25%	0%	72%	3%
CT	0%	0%	0%	100%	0%
DE	0%	0%	0%	100%	0%
FL	0%	0%	0%	99%	0%
GA	0%	1%	0%	99%	0%
HI	0%	10%	0%	90%	0%
ID	0%	13%	1%	86%	0%
IL	2%	14%	2%	83%	0%
IN	1%	17%	1%	81%	0%
IA	0%	13%	0%	87%	0%
KS	2%	23%	0%	76%	0%
KY	0%	1%	0%	99%	0%
LA	0%	1%	0%	99%	0%
ME	0%	0%	0%	100%	0%
MD	0%	4%	1%	95%	0%
MA	0%	0%	0%	100%	0%
MI	2%	22%	2%	75%	0%
MN	0%	13%	1%	85%	0%
MS	0%	1%	0%	99%	0%
MO	1%	1%	0%	98%	0%
MT	0%	3%	0%	97%	0%
NE	1%	31%	0%	68%	0%
NV	0%	5%	0%	95%	0%
NH	0%	0%	0%	100%	0%
NJ	0%	6%	0%	94%	0%
NM	0%	8%	0%	92%	0%
NY	0%	2%	0%	97%	0%
NC	0%	0%	1%	97%	1%
ND	0%	2%	0%	98%	0%
OH	1%	12%	1%	87%	0%
OK	0%	5%	0%	95%	0%
OR	0%	5%	0%	94%	0%
PA	0%	6%	0%	94%	0%
RI	0%	0%	0%	100%	0%
SC	0%	3%	0%	97%	0%
SD	1%	5%	0%	94%	0%
TN	0%	1%	0%	99%	0%
TX	0%	13%	0%	87%	0%
UT	0%	5%	0%	95%	0%
VT	0%	0%	0%	100%	0%
VA	0%	2%	0%	98%	0%
WA	0%	15%	0%	85%	0%
WV	0%	2%	0%	98%	0%
WI	0%	5%	0%	95%	0%
WY	0%	6%	0%	94%	0%
U.S. Average	<1%	10%	<1%	89%	0%

Source: See Section 8.

Table 7.4-3: Percentage Breakdown of Manure Management Systems for U.S. Dairy

STATE	Anaerobic Lagoon	Liquid/ Slurry	Daily Spread	Solid Storage	Other
AL	50%	0%	50%	0%	0%
AK	10%	71%	2%	2%	15%
AZ	50%	0%	0%	0%	50%
AR	25%	0%	75%	0%	0%
CA	40%	0%	0%	0%	60%
CO	5%	10%	85%	0%	0%
CT	0%	53%	47%	1%	0%
DE	5%	35%	60%	0%	0%
FL	30%	0%	10%	0%	60%
GA	35%	5%	5%	0%	55%
HI	31%	57%	6%	0%	6%
ID	10%	85%	2%	0%	3%
IL	5%	15%	45%	10%	25%
IN	10%	60%	20%	10%	0%
IA	3%	20%	8%	65%	4%
KS	0%	40%	60%	0%	0%
KY	19%	8%	30%	0%	43%
LA	6%	0%	4%	0%	90%
ME	0%	29%	58%	13%	0%
MD	2%	48%	45%	5%	0%
MA	0%	29%	58%	13%	0%
MI	5%	30%	45%	12%	8%
MN	0%	30%	40%	30%	0%
MS	10%	1%	2%	2%	85%
MO	60%	0%	40%	0%	0%
MT	12%	19%	39%	23%	7%
NE	0%	5%	35%	0%	60%
NV	40%	10%	0%	50%	0%
NH	0%	40%	20%	40%	0%
NJ	0%	29%	58%	13%	0%
NM	90%	0%	10%	0%	0%
NY	0%	20%	70%	10%	0%
NC	20%	20%	50%	10%	0%
ND	1%	1%	8%	90%	0%
OH	5%	30%	45%	12%	8%
OK	15%	0%	5%	0%	80%
OR	42%	35%	5%	1%	17%
PA	0%	2%	95%	3%	0%
RI	0%	29%	58%	13%	0%
SC	80%	5%	10%	5%	0%
SD	25%	25%	30%	20%	0%
TN	5%	40%	20%	0%	35%
TX	25%	10%	15%	50%	0%
UT	1%	1%	8%	90%	0%
VT	0%	29%	58%	13%	0%
VA	0%	75%	25%	0%	0%
WA	40%	50%	10%	0%	0%
WV	2%	40%	30%	20%	8%
WI	0%	15%	70%	15%	0%
WY	12%	19%	39%	23%	7%
U.S. Average	11%	21%	41%	18%	8%

Source: See Section 8.

Table 7.4-4. Percentage Breakdown of Manure Management Systems for U.S. Swine

STATE	Anaerobic Lagoon	Drylot	Pit Storage <1 month	Pit Storage >1 month	Other
AL	90%	0%	0%	10%	0%
AK	100%	0%	0%	0%	0%
AZ	100%	0%	0%	0%	0%
AR	70%	20%	0%	10%	0%
CA	90%	0%	0%	0%	10%
CO	24%	25%	21%	24%	6%
CT	15%	0%	0%	0%	85%
DE	20%	10%	0%	70%	0%
FL	35%	64%	1%	0%	0%
GA	68%	20%	0%	10%	2%
HI	32%	7%	17%	36%	8%
ID	40%	15%	5%	35%	5%
IL	25%	15%	10%	45%	5%
IN	25%	10%	5%	60%	0%
IA	3%	30%	11%	39%	13%
KS	30%	40%	0%	30%	0%
KY	80%	12%	7%	1%	0%
LA	95%	5%	0%	0%	0%
ME	3%	53%	2%	42%	0%
MD	50%	10%	0%	40%	0%
MA	3%	53%	2%	42%	0%
MI	42%	12%	4%	39%	3%
MN	0%	20%	20%	40%	20%
MS	59%	14%	5%	9%	13%
MO	80%	20%	0%	0%	0%
MT	0%	40%	25%	25%	10%
NE	35%	5%	55%	5%	0%
NV	25%	75%	0%	0%	0%
NH	5%	90%	0%	5%	0%
NJ	3%	53%	2%	42%	0%
NM	10%	70%	10%	10%	0%
NY	5%	30%	5%	60%	0%
NC	70%	15%	0%	15%	0%
ND	20%	20%	30%	30%	0%
OH	37%	8%	1%	46%	8%
OK	60%	30%	10%	0%	0%
OR	25%	6%	35%	12%	22%
PA	0%	39%	1%	60%	0%
RI	3%	53%	2%	42%	0%
SC	90%	5%	0%	5%	0%
SD	20%	30%	25%	25%	0%
TN	80%	15%	0%	5%	0%
TX	45%	30%	15%	10%	20%
UT	75%	25%	0%	0%	0%
VT	3%	53%	2%	42%	0%
VA	90%	0%	0%	10%	0%
WA	30%	0%	10%	60%	0%
WV	25%	25%	25%	25%	0%
WI	0%	10%	20%	70%	0%
WY	24%	25%	21%	24%	6%
U.S. Average	29%	20%	12%	32%	7%

Source: See Section 8.

Table 7.4-5. Percentage Breakdown of Manure Management Systems for U.S. Caged Layers

STATE	Anaerobic Lagoon	Deep Pit	Liquid/ Slurry	Other
AL	80%	10%	10%	0%
AK	15%	63%	12%	10%
AZ	0%	100%	0%	0%
AR	40%	0%	60%	0%
CA	7%	45%	3%	45%
CO	4%	88%	8%	0%
CT	0%	100%	0%	0%
DE	0%	100%	0%	0%
FL	12%	70%	6%	12%
GA	1%	30%	5%	65%
HI	80%	10%	0%	10%
ID	0%	40%	60%	0%
IL	10%	90%	0%	0%
IN	0%	95%	5%	0%
IA	2%	90%	4%	4%
KS	0%	100%	0%	0%
KY	61%	3%	33%	3%
LA	95%	0%	0%	5%
ME	0%	81%	9%	10%
MD	0%	100%	0%	0%
MA	0%	81%	9%	10%
MI	3%	85%	3%	10%
MN	0%	75%	25%	0%
MI	85%	0%	5%	10%
MO	0%	80%	20%	0%
MT	4%	88%	8%	0%
NE	0%	100%	0%	0%
NV	0%	75%	0%	25%
NH	0%	100%	0%	0%
NJ	0%	81%	9%	10%
NM	20%	45%	10%	25%
NY	0%	60%	30%	10%
NC	30%	15%	5%	50%
ND	5%	90%	5%	0%
OH	0%	100%	0%	0%
OK	0%	80%	20%	0%
OR	11%	80%	9%	0%
PA	0%	65%	5%	30%
RI	0%	81%	9%	10%
SC	40%	50%	0%	10%
SD	20%	80%	0%	0%
TN	7%	3%	90%	0%
TX	40%	10%	0%	50%
UT	0%	50%	0%	50%
VT	0%	81%	9%	10%
VA	0%	30%	0%	70%
WA	0%	90%	10%	0%
WV	0%	0%	0%	100%
WI	0%	55%	5%	40%
WY	4%	88%	8%	0%
U.S. Average	14%	56%	10%	20%

Source: See Section 8.

Table 7.4-6. Percentage Breakdown of Manure Management Systems for U.S. Broilers

State	Litter	Other
AL	100%	0%
AK		
AZ		
AR	100%	0%
CA	100%	0%
CO		
CT		
DE	100%	0%
FL	100%	0%
GA	100%	0%
HI	100%	0%
ID		
IL		
IN		
IA	100%	0%
KS		
KY	100%	0%
LA		
ME		
MA		
MD	100%	0%
MI	100%	0%
MN	100%	0%
MS	100%	0%
MO	100%	0%
MT		
NC	100%	0%
ND		
NH		
NJ		
NM		
NY	100%	0%
NE	100%	0%
NV		
OH	100%	0%
OK	100%	0%
OR	100%	0%
PA	100%	0%
RI		
SC	100%	0%
SD		
TN	100%	0%
TX	100%	0%
UT		
VA	100%	0%
VT		
WV	100%	0%
WA	100%	0%
WI	100%	0%
WY		
Other	100%	0%
U.S. Average	100%	0%

Table 7.4-7. Percentage Breakdown of Manure Management Systems for U.S. Turkeys

State	Litter	Range	Other
AR	95%	5%	0%
AK			
AZ			
AR			
CA	93%	7%	0%
CO			
CT	0%	100%	0%
DE			
FL			
GA	50%	50%	0%
HI			
ID			
IL	85%	15%	0%
IN	95%	5%	0%
IA	100%	0%	0%
KS	100%	0%	0%
KY			
LA			
ME			
MA	75%	25%	0%
MD	90%	10%	0%
MI	93%	7%	0%
MN	100%	0%	0%
MS			
MO	100%	0%	0%
MT			
NC	90%	10%	0%
ND	40%	60%	0%
NH	100%	0%	0%
NJ	75%	25%	0%
NM			
NY	100%	0%	0%
NE	100%	0%	0%
NV			
OH	100%	0%	0%
OK			
OR	100%	0%	0%
PA	90%	10%	0%
RI			
SC	95%	5%	0%
SD	100%	0%	0%
TN			
TX			
UT	0%	100%	0%
VA	94%	6%	0%
VT			
WV	90%	10%	0%
WA			
WI			
WY			
Other	88%	12%	0%
U.S. Average	92%	8%	0%

Source: See Section 8.

Table 7.4-8. Percentage Breakdown of Manure Management Systems for U.S. Sheep

STATE	Pasture	Other
AL		
AK	100%	0%
AZ	100%	0%
AR		
CA	90%	10%
CO	95%	5%
CT	50%	50%
DE		
FL		
GA		
HI		
ID	95%	5%
IL	95%	5%
IN	90%	10%
IA	99%	1%
KS	100%	0%
KY	95%	5%
LA	100%	0%
ME	66%	34%
MD	66%	34%
MA	66%	34%
MI	94%	6%
MN	90%	10%
MS		
MO	90%	10%
MT	98%	2%
NE	90%	10%
NV	98%	2%
NH	100%	0%
NJ	66%	34%
NM	100%	0%
NY	65%	35%
NC	98%	2%
ND	95%	5%
OH	95%	5%
OK	100%	0%
OR	91%	9%
PA	50%	50%
RI		
SC		
SD	100%	0%
TN	100%	0%
TX	80%	20%
UT	95%	5%
VT	66%	34%
VA	100%	0%
WA	100%	0%
WV	90%	10%
WI	97%	3%
WY	95%	5%
Other	100%	
U.S. Average	92%	8%

Table 7.4-9. Percentage Breakdown of Manure Management Systems for U.S. Goats

STATE	Pasture	Other
AL	100%	0%
AK	100%	0%
AZ	95%	5%
AR	99%	1%
CA	0%	100%
CO	100%	0%
CT	100%	0%
DE	100%	0%
FL	80%	20%
GA	100%	0%
HI	92%	8%
ID	92%	8%
IL	100%	0%
IN	100%	0%
IA	100%	0%
KS	100%	0%
KY	99%	1%
LA	100%	0%
ME	100%	0%
MD	100%	0%
MA	100%	0%
MI	99%	1%
MN	100%	0%
MS	95%	5%
MO	100%	0%
MT	99%	1%
NE	100%	0%
NV	98%	2%
NH	100%	0%
NJ	100%	0%
NM	100%	0%
NY	100%	0%
NC	90%	10%
ND	100%	0%
OH	100%	0%
OK	100%	0%
OR	84%	16%
PA	100%	0%
RI	100%	0%
SC	100%	0%
SD	100%	0%
TN	100%	0%
TX	80%	20%
UT	100%	0%
VT	100%	0%
VA	99%	1%
WA	100%	0%
WV	80%	20%
WI	95%	5%
WY	100%	0%
Other		
U.S. Average	84%	16%

Source: See Section 8.

Table 7.4-10. Percentage Breakdown of Manure Management Systems for U.S. Horses

STATE	Paddock	Pasture	Other
AL	50%	50%	0%
AK	10%	90%	0%
AZ	35%	65%	0%
AR	10%	90%	0%
CA	20%	80%	0%
CO	17%	83%	0%
CT	50%	50%	0%
DE	50%	50%	0%
FL	15%	60%	25%
GA	33%	60%	7%
HI	45%	55%	0%
ID	35%	60%	5%
IL	30%	40%	30%
IN	50%	50%	0%
IA	8%	92%	0%
KS	10%	90%	0%
KY	30%	70%	0%
LA	25%	75%	0%
ME	35%	65%	0%
MD	35%	65%	0%
MA	35%	65%	0%
MI	36%	64%	0%
MN	50%	50%	0%
MS	40%	60%	0%
MO	10%	90%	0%
MT	1%	99%	0%
NE	5%	95%	0%
NV	20%	80%	0%
NH	90%	10%	0%
NJ	35%	65%	0%
NM	75%	25%	0%
NY	50%	25%	25%
NC	10%	65%	25%
ND	30%	70%	0%
OH	95%	5%	0%
OK	20%	80%	0%
OR	45%	55%	0%
PA	50%	50%	0%
RI	35%	65%	0%
SC	50%	50%	0%
SD	20%	80%	0%
TN	25%	75%	0%
TX	0%	60%	40%
UT	20%	80%	0%
VT	35%	65%	0%
VA	1%	99%	0%
WA	50%	50%	0%
WV	75%	25%	0%
WI	15%	50%	35%
WY	17%	83%	0%
U.S. Average	27%	66%	7%

Source: See Section 8.

Table 7.4-11. U.S. Typical Animal Mass and Volatile Solids Production

Animal Type		Typical Animal Mass (TAM) [lbs.]	Volatile Solids (VS) [lbs. VS/lb. animal mass/yr]
Feedlot Beef Cattle	Steers/Heifers	915	2.6
Other Beef Cattle	Calves	397	2.6
	Steers/Heifers	794	2.6
	Cows	1102	2.6
	Bulls	1587	2.6
Dairy Cattle	Heifers	903	3.65
	Cows	1411	3.65
Swine	Market	101	3.1
	Breeding	399	3.1
Poultry	Layers	3.5	4.4
	Broilers	1.5	6.2
	Ducks	3.1	6.75
	Turkeys	7.5	3.32
Other	Sheep	154	3.36
	Goats	141	3.48
	Donkeys	661	3.65
	Horses and Mules	992	3.65
Source: ASAE 1995			

Table 7.4-12. Comparative Definitions of EIIP Cattle Categories and USDA Categories

EIIP Category		USDA Category	USDA Source for Data
Feedlot Beef Cattle	Steers/Heifers	Cattle on Feed	*Cattle on Feed*, January Inventory
Other Beef Cattle	Calves	Calves	*Cattle*, January Inventory
	Steers/Heifers	(Steers 500+ & Other Heifers & Beef Replacement Heifers) - (Total number of Cattle on Feed)	*Cattle*, January Inventory
	Cows	Beef Cows that have calved	*Cattle*, January Inventory
	Bulls	Bulls 500+	*Cattle*, January Inventory
Dairy Cattle	Heifers	Milk Replacement Heifers	*Cattle*, January Inventory
	Cows	Milk Cows that have calved	*Cattle*, January Inventory

Table 7.4-13. Estimates of Maximum Methane Producing Capacity (B_o) of U.S. Livestock

Animal Type	Category	Maximum Potential Emissions (Bo) (cf CH_4/lb-VS)
Cattle	Beef in Feedlots	5.29
	Beef Not in Feedlots	2.72
	Dairy	3.84
Swine	Breeder	5.77
	Market	7.53
Poultry	Layers	5.45
	Broilers	4.81
	Turkeys	4.81
	Ducks	5.13
Sheep	In Feedlots	5.77
	Not in Feedlots	3.04
Goats		2.72
Horses & Mules		5.29

Source: See Section 8.

Table 7.4-14. State-Specific Methane Conversion Factors for the Most Commonly Used Manure Management Systems in the U.S.

State	Pasture, Range & Paddocks	Drylot	Solid Storage	Daily Spread	Liquid/Slurry
Alabama	1.4%	1.9%	1.%	0.4%	29.0%
Arizona	1.4%	1.9%	1.4%	0.4%	28.9%
Arkansas	1.3%	1.8%	1.3%	0.4%	27.6%
California	1.2%	1.4%	1.2%	0.3%	21.9%
Colorado	0.9%	1.0%	0.9%	0.2%	18.2%
Connecticut	0.9%	1.0%	0.9%	0.2%	18.5%
Delaware	1.2%	1.4%	1.2%	0.3%	22.6%
Florida	1.5%	2.4%	1.5%	0.6%	38.6%
Georgia	1.4%	1.8%	1.4%	0.4%	29.0%
Idaho	0.8%	0.8%	0.8%	0.2%	15.5%
Illinois	1.1%	1.3%	1.1%	0.3%	22.8%
Indiana	1.0%	1.2%	1.0%	0.3%	21.5%
Iowa	0.9%	1.1%	0.9%	0.2%	20.7%
Kansas	1.1%	1.5%	1.1%	0.3%	24.7%
Kentucky	1.2%	1.5%	1.2%	0.3%	23.8%
Louisiana	1.4%	2.1%	1.4%	0.5%	32.5%
Maine	0.8%	0.8%	0.8%	0.2%	15.5%
Maryland	1.1%	1.2%	1.1%	0.3%	21.0%
Massachusetts	0.9%	1.0%	0.9%	0.2%	18.1%
Michigan	0.8%	0.9%	0.8%	0.2%	17.0%
Minnesota	0.8%	0.8%	0.8%	0.2%	18.0%
Mississippi	1.4%	1.9%	1.4%	0.4%	29.3%
Missouri	1.1%	1.4%	1.1%	0.3%	24.1%
Montana	0.7%	0.8%	0.7%	0.2%	15.8%
Nebraska	1.0%	1.1%	1.0%	0.2%	20.8%
Nevada	1.2%	1.4%	1.2%	0.3%	22.1%
New Hampshire	0.8%	0.8%	0.8%	0.2%	16.3%
New Jersey	1.0%	1.1%	1.0%	0.3%	20.6%
New Mexico	1.2%	1.3%	1.2%	0.3%	21.3%
New York	0.9%	0.9%	0.9%	0.2%	18.1%
North Carolina	1.3%	1.5%	1.3%	0.3%	24.5%
North Dakota	0.7%	0.7%	0.7%	0.2%	16.8%
Ohio	1.0%	1.1%	1.0%	0.2%	20.2%
Oklahoma	1.4%	1.9%	1.4%	0.4%	28.7%
Oregon	1.1%	1.1%	1.1%	0.2%	16.2%
Pennsylvania	0.9%	1.0%	0.9%	0.2%	18.7%
Rhode Island	1.0%	1.1%	1.0%	0.2%	18.7%
South Carolina	1.3%	1.7%	1.3%	0.4%	27.3%
South Dakota	0.8%	0.9%	0.8%	0.2%	19.1%
Tennessee	1.3%	1.6%	1.3%	0.3%	24.8%
Texas	1.4%	2.1%	1.4%	0.5%	31.7%
Utah	0.9%	1.0%	0.9%	0.2%	17.4%
Vermont	0.8%	0.8%	0.8%	0.2%	16.6%
Virginia	1.2%	1.4%	1.2%	0.3%	22.5%
Washington	1.0%	1.0%	1.0%	0.2%	15.5%
West Virginia	1.2%	1.3%	1.2%	0.3%	21.4%
Wisconsin	0.8%	0.8%	0.8%	0.2%	17.0%
Wyoming	0.8%	0.8%	0.8%	0.2%	15.9%

Other Systems: Pit Storage for less than 30 days is assumed to have a methane conversion factor (MCF) equal to 50% of the MCF for Liquid/Slurry. Pit Storage for more than 30 days is assumed to have an MCF equal to liquid/slurry. Anaerobic lagoons are assumed to have an MCF of 90%; litter and deep pit stacks an MCF of 10%.

Source: See Section 8.

Table 7.4-15. State-Specific Methane Conversion Factors for Other Manure Management Systems Used in the U.S.

STATE	DAIRY	BEEF	SWINE	OTHER
AL	0%	0%	0%	0%
AK	75%	0%	0%	10%
AZ	10%	0%	0%	0%
AR	0%	0%	0%	0%
CA	10%	0%	10%	10%
CO	0%	90%	10%	0%
CT	0%	0%	10%	0%
DE	0%	0%	0%	0%
FL	0%	0%	0%	10%
GA	18%	0%	10%	10%
HI	10%	0%	10%	90%
ID	10%	10%	10%	0%
IL	10%	0%	10%	0%
IN	0%	0%	0%	0%
IA	10%	0%	20%	10%
KS	0%	0%	0%	0%
KY	0%	0%	0%	10%
LA	11%	0%	0%	10%
ME	0%	0%	0%	10%
MD	0%	0%	0%	0%
MA	0%	0%	0%	10%
MI	10%	0%	10%	10%
MN	0%	0%	20%	0%
MS	11%	0%	10%	20%
MO	0%	0%	0%	0%
MT	10%	0%	10%	0%
NE	12%	0%	0%	0%
NV	0%	0%	0%	10%
NH	0%	0%	0%	0%
NJ	0%	0%	0%	10%
NM	0%	0%	0%	10%
NY	0%	10%	0%	10%
NC	0%	20%	0%	10%
ND	0%	0%	0%	0%
OH	10%	0%	10%	0%
OK	40%	0%	0%	0%
OR	20%	0%	20%	0%
PA	0%	0%	0%	20%
RI	0%	0%	0%	10%
SC	0%	0%	0%	10%
SD	0%	0%	0%	0%
TN	20%	0%	0%	0%
TX	0%	0%	20%	20%
UT	0%	0%	0%	10%
VT	0%	0%	0%	10%
VA	0%	0%	0%	10%
WA	0%	0%	0%	0%
WV	10%	0%	0%	30%
WI	0%	0%	0%	20%
WY	10%	0%	10%	0%

Source: See Section 8.

Table 7.4-16 Worksheet to Calculate CH_4 Emissions from Manure Management
(Use one worksheet for each type of animal)

	Input	*Input*	*Input*	*(A)x(B)x(C)*	*Input*	*(D) x (E)*
	(A)	(B)	(C)	(D)	(E)	(F)
Animal Type	Population (head)	Typical Animal Mass (TAM) (lbs/head)	Volatile Solids (VS) (lbs. VS/lb. mass)	Total VS Produced (lbs)	Methane Producing Capacity (Bo) (cubic ft/lb-VS)	Maximum Potential Methane Emissions (cubic ft)

	Input	*Input*	*(F)x(G)x(H)*	*(I) x 0.0413*
	(G)	(H)	(I)	(J)
Manure System	Methane Conversion Factor (MCF) (%)	Waste System Usage (WS%) (%)	Methane Emissions (cubic ft)	Methane Emissions (lbs.)
Pasture/Range				
Daily Spread				
Solid Storage				
Drylot				
Deep Pit Stacks				
Litter				
Paddock				
Liquid/Slurry				
Anaerobic Lagoon				
Pit Storage <1 mo				
Pit Storage >1 mo				

Total Methane Emissions (tons/yr):

[Sum Column (J) and divide by 2000]

4.2 N_2O EMISSIONS FROM MANURE MANAGEMENT

N_2O emissions from animal production are divided into two methodologies, addressed in separate chapters of this volume. The methods for calculating direct emissions of N_2O from daily spread operations and from manure that is excreted directly on pasture, range, and paddock are presented in chapter 9 of this volume, in sections 4.1.3 and 4.2, respectively. These emissions are considered to be emissions from agricultural soils, whereas emissions from other animal waste management systems are not directly attributable to soils and are addressed in this chapter.

Step (1) Obtain Required Data

- *Required Data*. The information needed to estimate direct N_2O emissions from manure management consists of: animal population for each type of animal, typical animal mass (TAM), Kjeldahl nitrogen[6] emitted per unit of animal mass, and the percent of manure managed in each type of manure management system.

- *Data Sources*. Departments within each state responsible for conducting agricultural research and monitoring agricultural waste practices should be consulted for animal population data. Alternatively, animal population data are provided by the National Agriculture Statistics Service of the U.S. Department of Agriculture (USDA) and may be found at the following Internet address:
  http://usda.mannlib.cornell.edu/cgi-usda/agency.cgi?nass
  Animal population data may also be found in the *Census of Agriculture, Volume 1: Geographic Area Series*, published by the Bureau of the Census. Table 9.4-1 in chapter 9 of this volume provides data on typical animal mass and total Kjeldahl nitrogen excreted per unit of animal mass for each animal type. The percent of manure managed in various systems can be found in Tables 7.4-2 to 7.4-10. Where state data are available, they may be used in place of these default values.

- *Units for Reporting Data*. Animal populations should be reported in number of head.

Step (2) Calculate the Amount of Manure Managed

First calculate the amount of Kjeldahl nitrogen excreted by the state's livestock that is managed. To do so, for each animal type *i*, multiply population by

(1) the typical animal mass (TAM) for animal type *i*, in units of 1,000 kilograms (using data from Table 7.4-10 and dividing by 1000),
(2) the daily rate of Kjeldahl nitrogen excreted by animal type *i* per 1,000 kilograms of animal mass (found in chapter 9, Table 9.4-1),
(3) the percent of manure that is managed—i.e., not applied through daily spread operations nor deposited on pasture, range, or paddock (from Tables 7.4-2 through 7.4-10), and
(4) 365 days per year.

[6] Total Kjeldahl nitrogen is a measure of organically bound nitrogen and ammonia nitrogen.

The formula is shown below. Then sum the results across all animal types, to yield total Kjeldahl nitrogen excreted in managed manure.

Total Kjeldahl N Excreted by Animal Type$_i$ (kg/yr)	=	Population of Animal Type$_i$ (head)	x	(Average TAM (kg) /1000)	x	Kjeldahl N per day per 1000 kg mass (kg/day)	x	Percent of Managed Manure$_i$	x	365 days/yr

Next, adjust the total Kjeldahl nitrogen excreted in managed manure to account for the portion that volatilizes to NH_3 and NO_x, i.e., 20 percent (IPCC 1997). To do so, multiply the product of the equation above by (1-0.20) or 0.80, as shown in the equation below.

Example Suppose the number of dairy cows in Ohio in a given year was 300,000 head. According to Table 7.4-3, 55 percent of manure from dairy cows is managed (as defined above to exclude daily spread). Table 9.4-1 shows the average animal mass for dairy cows is 680 kg, and the Kjeldahl N per 1000 kg mass for dairy cows is estimated to be 0.45 kg/day. Therefore, the amount of nitrogen produced by dairy cows in Ohio during the year would be calculated as follows:

300,000 head x 55 percent x ((680 kg/head)/1000)
x 0.45 kg Kjeldahl N per 1000 kg mass per day x 365 days/year
=18.4 million kilograms per year of Kjeldahl nitrogen

Next, adjust for nitrogen that volatilizes to NH_3 and NO_x by multiplying by 0.80:

18.4 million kg/yr of Kjeldahl N x 0.80 = **14.7 million kg/yr unvolatilized N**

Unvolatilized N from Managed Manure (kg N)	=	Total Kjeldahl N Excreted in Managed Manure (kg N)	x	0.80

Step (3) Calculate N_2O Emissions from Manure Management

The direct N_2O emissions from animal production can be calculated by multiplying the unvolatilized nitrogen from managed animal waste by the appropriate IPCC default emission factor, for each manure management system.

- Emission factor for anaerobic lagoons and liquid systems = 0.001 kg N_2O-N/kg N (IPCC 1997); and

- Emission factor for solid storage, drylot, and other[7] = 0.02 kg N_2O-N/kg N (IPCC 1997, US EPA 1998)

Total N_2O Emissions from Each Manure Management System (kg N_2O-N)	=	Unvolatilized N from Manure Managed in that System (kg N)	x	Emission Factor for N_2O Emissions for that System (kg N_2O-N/kg N)

Then sum across all manure management systems, to obtain total N_2O emissions from manure management.

To convert units from kg N_2O-N to metric tons of carbon equivalent (MTCE) of N_2O, use Table 7.4-17. First, enter the total emissions, in units of kilograms of N_2O-N, in column A. Then multiply by 44/28 to convert to units of kilograms of N_2O (column B). Then convert to units of metric tons of carbon equivalent (MTCE) as shown in column C. First divide by 1,000 to obtain the number of metric tons of N_2O. Then multiply the number of metric tons of N_2O by (1) a factor of 310 (the GWP for N_2O) and (2) 12/44 (the ratio of the atomic weight of carbon to the molecular weight of CO_2).

Table 7.4-17. Worksheet to Calculate N_2O Emissions from Manure Management

Source of Emissions	**A: Emissions from Manure Management (kg N_2O-N/kg N)**	**B: Total Emissions of N_2O (kg N_2O/yr)**	**C: MTCE**
		B = A x (44/28)	C= (B/1000) x 310 x 12/44
Emissions from Manure Management			

[7] Although the IPCC guidelines (IPCC 1997) include emissions from solid storage and drylot under agricultural soils, the U.S. greenhouse gas inventory (U.S. EPA 1998) includes these sources under manure management; this chapter conforms to the U.S. inventory approach. Additionally, the U.S. inventory notes that the IPCC's value of 0.005 kg N_2O-N/ kg N excreted, for "other" systems (IPCC 1997), is inconsistent with the characteristics of "other" management systems. This chapter follows the precedent established in the U.S. Inventory and uses the emission factor for soil storage/drylot in place of the emission factor for "other" systems.

5

ALTERNATIVE METHODS FOR ESTIMATING EMISSIONS

No alternative methods have yet been approved by the Greenhouse Gas Committee of the Emission Inventory Improvement Program.

6

QUALITY ASSURANCE/QUALITY CONTROL

Quality assurance (QA) and quality control (QC) are essential elements in producing high quality emission estimates and should be included in all methods to estimate emissions. QA/QC of emissions estimates are accomplished through a set of procedures that ensure the quality and reliability of data collection and processing. These procedures include the use of appropriate emission estimation methods, reasonable assumptions, data reliability checks, and accuracy/logic checks of calculations. Volume VI of this series, *Quality Assurance Procedures*, describes methods and tools for performing these procedures.

The preferred method described above for estimating CH_4 emissions from animal manure is based on sound scientific data and experimental evidence. To the extent possible, emissions should be estimated with as much information as possible about the conditions under which animal manure is managed. This is particularly important when manure is managed under anaerobic conditions, such as lagoons or other liquid/slurry systems.

The estimates and assumptions used by Safley et al. (1992a) are instructive for identifying the potential magnitude of emissions and the relative importance of various animals and manure management systems. However, where information that is specific to the individual state is available, it should be used.

The weakest link in the method presented here is the set of estimates of the CH_4 conversion factors (MCFs) for the individual manure management systems. Very few field measurements are available upon which to base these estimates, particularly for “dry” management systems such as dry lots, pastures, and paddocks. The MCFs for the “wet” management systems such as lagoons and slurry storage have a much stronger foundation. The inaccuracy in the emissions estimates due to this lack of data cannot be quantified. Emissions estimates can be improved significantly once comprehensive field measurements are performed.

6.1 DATA ATTRIBUTE RANKING SYSTEM (DARS) SCORES

DARS is a system for evaluating the quality of data used in an emission inventory. To develop a DARS score, one must evaluate the reliability of eight components of the emissions estimate. Four of the components are related to the activity level (e.g., the amount of each type of manure). The other four components are related to the emission factor (e.g., the amount of CH_4 emitted by a ton of a given type of manure managed by a given method). For both the activity level and the emission factor, the four attributes evaluated are the measurement method, source specificity, spatial congruity, and temporal congruity. Each component is scored on a scale of zero to one, where one represents a high level of reliability. To derive the DARS score for a given estimation method, the activity level score is multiplied by the emission factor score for each of the four attributes, and the resulting products are averaged. The highest possible DARS composite score is one. A complete discussion of DARS may be found in Chapter 4 of Volume VI, *Quality Assurance Procedures*.

The DARS scores provided here are based on the use of the emission factors provided in this chapter, and activity data from the US government sources referenced in the various steps of the methodology. If a state uses state data sources for activity data, the state may wish to develop a DARS score based on the use of state data.

TABLE 7.6-1

DARS SCORES: CH_4 EMISSIONS FROM MANURE MANAGEMENT

DARS Attribute Category	Emission Factor Attribute	Explanation	Activity Data Attribute	Explanation	Emission Score
Measurement	3	Because the emission factor is not based on measurement, the highest possible score is 5. Since the factor is derived from laboratory and field measurements, applying the DARS formula the score would be 5. However, only a few measurements have been taken.	8	Data on annual average animal populations are estimated based on state and national data.	0.24
Source Specificity	10	The emission factors were developed specifically for the intended emission source (i.e., emission factors were developed for each manure management system).	7	The activity measured, average animal population, is highly correlated to the emissions activity.	0.70
Spatial Congruity	6	Methane conversion factors are developed for each type of manure management system in each state, but the factors account in only a rough way for the state-by-state variability in average temperature. For lagoons, a single factor is used that does not account for temperature differences among states.	8	States use state-level activity data or proxy data for similar states to estimate state-wide emissions; spatial variability is expected to be low to moderate.	0.48
Temporal Congruity	3	The emission factors are based on field and laboratory tests that presumably did not cover an entire year. The temporal variability over the course of a year is expected to be high.	7	States use annual activity data to estimate annual emissions, but the percentage breakdowns for manure management systems are based on data from the early 1990s.	0.21
				Composite Score	**0.41**

TABLE 7.6-2

DARS SCORES: N_2O EMISSIONS FROM MANURE MANAGEMENT

DARS Attribute Category	Emission Factor Attribute	Explanation	Activity Data Attribute	Explanation	Emission Score
Measurement	3	IPCC 1997 states that the emission factors (kg N2O-N per kg N excreted) were based on a very limited amount of information; no further information is provided regarding how the emission factors were developed.	8	Data on annual average animal populations are estimated based on state and national data.	0.24
Source Specificity	10	Emission factors were developed for each type of manure management system.	7	The activities measured--average animal population and percentage of manure managed using each management system--are highly correlated to the emissions activity.	0.70
Spatial Congruity	7	Single, global emission factors were developed; spatial variability is expected to be moderate.	8	States use state-level activity data or proxy data for similar states to estimate state-wide emissions; spatial variability is expected to be low to moderate.	0.56
Temporal Congruity	7	Assuming that the limited amount of information used was generated by less than full-year measurements; temporal variability is expected to be low to moderate.	7	States use annual activity data to estimate annual emissions, but the percentage breakdowns for manure management systems are based on data from the early 1990s.	0.49
				Composite Score	**0.50**

7

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8

APPENDIX: NOTES ON DATA SOURCES

This section describes how values were developed for manure management (as shown in Tables 7.4-2 through 7.4-10), maximum CH_4-producing capacity (B_o) (as shown in Table 7.4-13), and methane conversion factors (MCF) (as shown in Tables 7.4-14 and 7.4-15).

Livestock Manure Management System Usage (WS%)

Livestock manure management system usage in the United States was determined by obtaining information from staff of the U.S. Department of Agriculture's Agricultural Extension Service in each state. The U.S. was divided into eleven geographic regions based on similarities of climate and livestock production, as shown in Table 7.8-1. For states that did not provide information, the regional average manure system usage was assumed. Where a state did not give data for some animal types, a regional average was used for those animal types.

Table 7.8-1
Regions of the U.S. for Manure Management Characterization

Northeast	Connecticut*, Maine, Massachusetts, New Hampshire*, New Jersey, New York*, Pennsylvania, Rhode Island, Vermont
Southeast	Delaware*, Florida*, Georgia*, Maryland, North Carolina*, South Carolina*, Virginia*, West Virginia*
Plains	Colorado*, Kansas*, Montana*, Nebraska*, North Dakota*, South Dakota*, Wyoming
South	Alabama*, Arkansas*, Kentucky, Louisiana*, Mississippi*, Tennessee*,
Southwest	New Mexico*, Oklahoma*, Texas*
Midwest	Illinois*, Indiana*, Michigan, Ohio*, Wisconsin*, Iowa*, Minnesota*, Missouri*
Northwest	Idaho*, Oregon*, Washington*
Far West	Arizona*, Nevada, Utah*
Pacific West	California*
North Pacific	Alaska*
Pacific Islands	Hawaii*

* States that have supplied estimates of the usage of various manure management systems for manure from different types of animals.

Maximum CH_4 Producing Capacity (B_o)

The maximum amount of CH_4 that can be produced per pound of VS (B_o) varies by animal type and diet. Measured B_o values for beef manure range from 2.72 cubic feet of CH_4 per pound of VS (ft^3/lb-VS) for a corn silage diet to 5.29 ft^3/lb-VS for a corn-based high energy diet that is typical of feedlots. Table 7.8-2 presents B_o values obtained from the literature.

Table 7.8-2 Maximum CH_4-Producing Capacity for U.S. Livestock Manure			
Animal Type	Diet	B_o (ft^3 CH_4/lb-VS)	Reference
Beef	7% corn silage, 87.6% corn	4.65	Hashimoto et al. (1981)
Beef	Corn-based high energy	5.29	Hashimoto et al. (1981)
Beef	91.5% corn silage, 0% corn	2.72	Hashimoto et al. (1981)
Beef		3.68	Hill (1984)
Beef		5.29	Chen, et al. (1980)
Dairy	58-68% silage	3.84	Morris (1976)
Dairy	72% roughage	2.72	Bryant et al. (1976)
Dairy		2.24	Hill (1984)
Dairy	Roughage, poor quality	1.60	Chen, et al. (1988)
Horse		5.29	Ghosh (1984)
Poultry	Grain-based ration	6.25	Hill (1982)
Poultry		5.77	Hill (1984)
Poultry		3.84	Webb & Hawkes (1985)
Poultry		3.84	Hawkes & Young (1980)
Swine	Barley-based ration	5.77	Summers & Bousfield (1980)
Swine	Corn-based high energy	7.69	Hashimoto (1984)
Swine		5.13	Hill (1984)
Swine	Corn-based high energy	8.33	Kroeker et al. (1984)
Swine	Corn-based high energy	7.69	Stevens & Schulte (1979)
Swine	Corn-based high energy	7.53	Chen (1983)
Swine	Corn-based high energy	7.05	Iannotti et al. (1979)
Swine	Corn-based high energy	7.21	Fischer et al. (1975)

Appropriate B_o values were selected for this chapter depending on the typical diet of each animal type and category. For animal types without B_o measurements, the B_o was estimated based on similarities with other animals. Ruminants for which there were no values in the literature were assumed to have the same values as cattle, except in the case of sheep, which were assumed to have B_o values 10 percent higher than cattle (Jain et al. 1981). Table 7.4-13 lists the values selected for this chapter.

Methane Conversion Factors (MCFs)

The methane conversion factor depends on the manure management system used, and the average temperature.

A variety of manure management practices are in use throughout the U.S. The following is a brief description of the major livestock manure management systems in use.

Pasture/Range The manure from animals grazing on pasture is allowed to remain on the pasture, and is not managed.

Daily Spread The manure is collected in solid form, with or without bedding, by some means such as scraping, then stored until applied to fields on a regular basis.

Paddock Horses are frequently kept in paddocks where they are confined to a limited area, but not confined to stalls; this manure will be essentially the same as manure on pasture or drylot.

Solid Storage The solid manure is collected as in the daily spread system, but this collected manure is stored in bulk for a long period of time (months) before any disposal.

Drylot In dry climates, animals may be kept on unpaved feedlots where the manure is allowed to dry until it is periodically removed. Upon removal the manure may be spread on fields.

Deep Pit Stacks With caged layers the manure may be allowed to collect in solid form in deep pits (several feet deep) below the cages. The manure in the pits may only be removed once a year. This manure is generally dry.

Litter Broilers and young turkeys may be grown on beds of litter such as shavings, sawdust, or peanut hulls, with the manure/litter pack removed periodically between flocks. This manure will not generally be as dry as with deep pits, but will still be in solid form.

Liquids/Slurry These systems generally use large concrete-lined tanks built into the ground. Manure is stored in the tank for six or more months until it can be applied to fields. To facilitate handling as a liquid, water usually must be added to the manure, reducing its total solids concentration to less than 12 percent.

Anaerobic Lagoon Anaerobic lagoon systems are generally characterized by automated flush systems that use water to transport the manure to treatment lagoons that are usually greater than six feet deep. The manure resides in the lagoon for periods ranging from 30 days to over 200 days, depending on the lagoon design and other local conditions. The water from the lagoon is often recycled as flush water. Periodically the lagoon water may be used for irrigation on fields with the treated manure providing fertilizer value.

Pit Storage Liquid swine manure may be stored in a pit while awaiting final disposal. The pits are often constructed beneath the swine building. The length of storage time varies, and for this analysis is divided into two categories: less than one month or greater than one month.

The extent to which the maximum CH_4 producing capacity (B_o) is realized for a given livestock manure management system and climate conditions is defined as the Methane Conversion Factor (MCF) for the manure system. For example, a manure system that produces no CH_4 emissions will have an MCF of 0. A manure system can be characterized based on the total solids content of the manure:

- <u>Solid systems</u> have a total solids content of 20 percent or more.

- <u>Liquid/slurry systems</u> have a total solids content less than 20 percent.

Manure as excreted may have a total solids content ranging from 9 to 30 percent (Taiganides 1987). The solids content may be increased to facilitate handling, by adding an absorbent bedding material. Alternatively, water may be added to lower the total solids content, to allow for liquid transport and handling.

These classifications of systems are particularly important in estimating the potential for CH_4 production from the manure. Liquid and slurry systems will typically involve anaerobic conditions, which result in CH_4 production. Solid systems promote conditions that limit CH_4 production even if anaerobic conditions may exist.

Safley et al. (1992a) reviewed the literature to investigate the appropriate range of MCF values for U.S. manure management systems. Although data were available for some systems, MCF values were required for many more systems. To improve the MCF estimates, the U.S. Environmental Protection Agency sponsored analysis to better estimate the MCF for several key livestock manure systems. Preliminary findings from this analysis indicate that:

- The estimated MCF value of <u>dry</u> *in situ* pasture, range, paddock, and solid storage manure is 1 to 2 percent. The estimated MCF for drylot manure is 1 to 5 percent. However, the analysis did not consider the effect of moisture, nor emissions that may result when the manure is washed into streams, rivers, and lakes or incorporated into the soil (Hashimoto 1992).

- The MCF value for liquid/slurry and pit storage varies greatly by temperature, ranging from about 10 percent at 50EF to 65 percent at 86EF (Hashimoto 1992).

- The MCF value for daily spread is less than 1 percent (Hashimoto 1992).

- The MCF value for anaerobic lagoons is about 90 percent. This estimate is based on continuous CH_4 measurements taken over a two and one-half year period at a North Carolina dairy farm (Safley 1991).

The MCF values for each manure management system at various temperatures are listed in Table 7.8-3.

Table 7.8-3
Methane Conversion Factors for Various Manure Management Systems at Various Temperatures

MCFs based on laboratory measurement	MCF at 30EC	MCF at 20E	MCF at 10EC
Pasture, Range, Paddocks [A]	2%	1.5%	1%
Liquid/Slurry [A]	65%	35%	10%
Pit Storage < 30 days [A]	33%	18%	5%
Pit Storage > 30 days [A]	65%	35%	10%
Drylot [B]	5%	1.5%	1%
Solid Storage [A]	2%	1.5%	1%
Daily Spread [A]	1%	0.5%	0.1%
MCF measured by long-term field monitoring	**Average Annual MCF**		
Anaerobic Lagoons [C]	90%		
MCFs estimated by Safley et al.	**Average Annual MCF**		
Litter [D]	10%		
Deep Pit Stacking [D]	5%		

[A] Hashimoto (1992).
[B] Based on Hashimoto (1992).
[C] Safley at al. (1992a) and Safley (1992b).
[D] Safley et al. (1992a).

The MCF for an individual state will depend on the average monthly temperature and is calculated by:

- Estimating the average monthly temperature in each climate division;[8]

- Estimating the MCF value for the system for each climate division for each month using the average temperature data and the MCF values listed in Table 7.8-3;

- Estimating the annual MCF for the system for each climate division by averaging the monthly climate division estimates; and

- Estimating the state-wide MCF for the system by weighting the average MCF for each climate division by the fraction of the state's livestock manure managed by the system in each climate division (estimated based on dairy population in each climate division).[9]

This approach was used to estimate the state-specific MCF values for each manure management system, as shown in Tables 7.4-14 and 7.4-15.

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[8] The average temperature in each climate division of each state was calculated for the period of 1951 to 1980 using the National Climatic Data Center (NCDC) time-bias corrected Historical Climatological Series Divisional Data (NCDC 1991).

[9] The dairy population in each climate division were estimated using the dairy population in each county (Bureau of the Census 1987) and detailed county and climate division maps (NCDC 1991). Using the dairy population as a weighting factor will result in relatively accurate MCFs for manure from dairy animals, but less accurate MCFs for manure from other livestock.